

1. FINAL PUBLISHABLE SUMMARY REPORT

“NEW PROCESS AND MACHINERY FOR MICROPARTS MOULDING BASED ON ULTRASOUND EXCITATION”: SONOPLAST



1.1 INTRODUCTION, BACKGROUND AND GOALS

INTRODUCTION

Optics, Biotechnology and Microelectronic are currently critical fields in which technologies for **large scale microfabrication** present a strategic interest to gain technology and economic benefits for Europe.

In this context, injection moulding processes have been shown as one of the most precise, flexible and cost efficient technologies for part replication at large scale. However, the current technologies applied to the microscale by most of manufacturers of injection machines are mainly based on the same concepts (process and tooling) used for the injection of bigger parts. By one side, this explains the limitations of the current approach in terms of dosage precision, process accuracy and repetitiveness. But now, **a completely revolutionary concept of plastification and moulding process has been developed**. The project Sonoplast introduces the first ultrasound injection moulding machine exclusively designed for the replication of microparts.

The state-of-the-art shows the use of ultrasounds in the field of plastics is not new. Examples of applications include welding of plastic components (installed on the machine nozzle to enhance melting flow); ultrasounds based ejection systems implemented in the mould, and others. Likewise, ultrasounds can also be used for melting reduced volumes of thermoplastics. In spite of this, no commercial applications have been brought to market so far, **what confirms the innovation of Sonoplast Project's initiative**.

BACKGROUND

Ascamm's previous trials confirmed that it was possible to fill tiny cavities of a mould with plastic melted through an ultrasound piezoelectric transducer. This equipment acts providing heat for melting the polymer while producing the required filling pressure. Taking only few tenths of a second, the energy provided by the ultrasounds also allows filling the mould applying significantly less pressure compared to solutions currently in use.

Mentioned advantages were critical when deciding to set up **Sonoplast** consortium aiming at developing the first ultrasound microinjection machine. Based on such results, it was feasible to think of a **compact moulding machine**, as the clamping force can be provided by small electric motors.

Another important advantage to consider involves eliminating the plastification unit. Along with the reduction of the sprue volume, those characteristics represent an important cost advantage in terms of raw material and power consumption. The ultrasound transducer gives more energetic efficiency to the process than the electrical heater bands used in conventional injection moulding. Finally, the shorter cycle time exposes the raw material to a significant less risk of plastic degradation, reducing the waste.

GOALS

The original objective of **Sonoplast**, now successfully achieved, was **the development of the first ultrasounds moulding machine for the production of micro and mini plastic parts**. Such development followed a new concept of mould and plastic feeding system adapted to the physical principles of ultrasounds and mechanical features (kinematics) of the new moulding machine.

The steps initially proposed for overcoming those challenges were established as follows:

1. Study of the influence on the **plastic melt rheology** of the ultrasounds parameters. Determination of the most important process variables and their impact on the plastic melt behaviour;
2. Development of the **ultrasound moulding machine** mechanical concept;
3. Development of the **new mould concept**;
4. Development of the **feeding system**;
5. Development of the **process control** strategies and systems adapted to ultrasound moulding machine and implementation of the sensor system needed. **Process reliability**.
6. **Automatic handling** of the micro moulded parts and part **quality reliability**;
7. Monitoring of the evolution and matching of the developed technology and the **market trends**.

PARTICIPANTS

Participant no. *	Participant organisation short name	Participant organisation name	Country
1 (Coordinator)	ASCAMM	Fundació Privada Ascamm (RTD)	Spain
2	PROMOLDING	Promolding BV (SME)	Netherlands
3	PLASTIA	Plastiasite S.A (SME)	Spain
4	MATEU	Mateu y Solé S.A (SME)	Spain
5	CEDRAT	Cedrat Technologies S.A. (RTD)	France
6	FRAUNHOFER	Fraunhofer-Gesellschaft zur	Germany
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1.2 DESCRIPTION OF THE NEW TECHNOLOGY

The new Ultrasound Moulding Machine works with a 1000W generator and a 30 KHz working frequency.

The acoustic unit is composed by the following elements:

- Transducer: converts the electrical energy into kinetic energy (creating the ondulatory movement);
- Booster: amplifies or reduces the amplitude of the wave;
- Sonotrode: transfers the vibratory energy to the material as well as provides the necessary pressure to inject it into the mould.

The vibratory energy generated depends on the amplitude level at the sonotrode tip. On the other hand, the ultrasound generator allows tuning the amplitude values depending on the type of plastic material to be melted. The energy transferred through the sonotrode heats and melts the material until it reaches a proper viscosity value that allows filling the mould cavities. The **figure 1** clearly depicts the acoustic unit assembly.

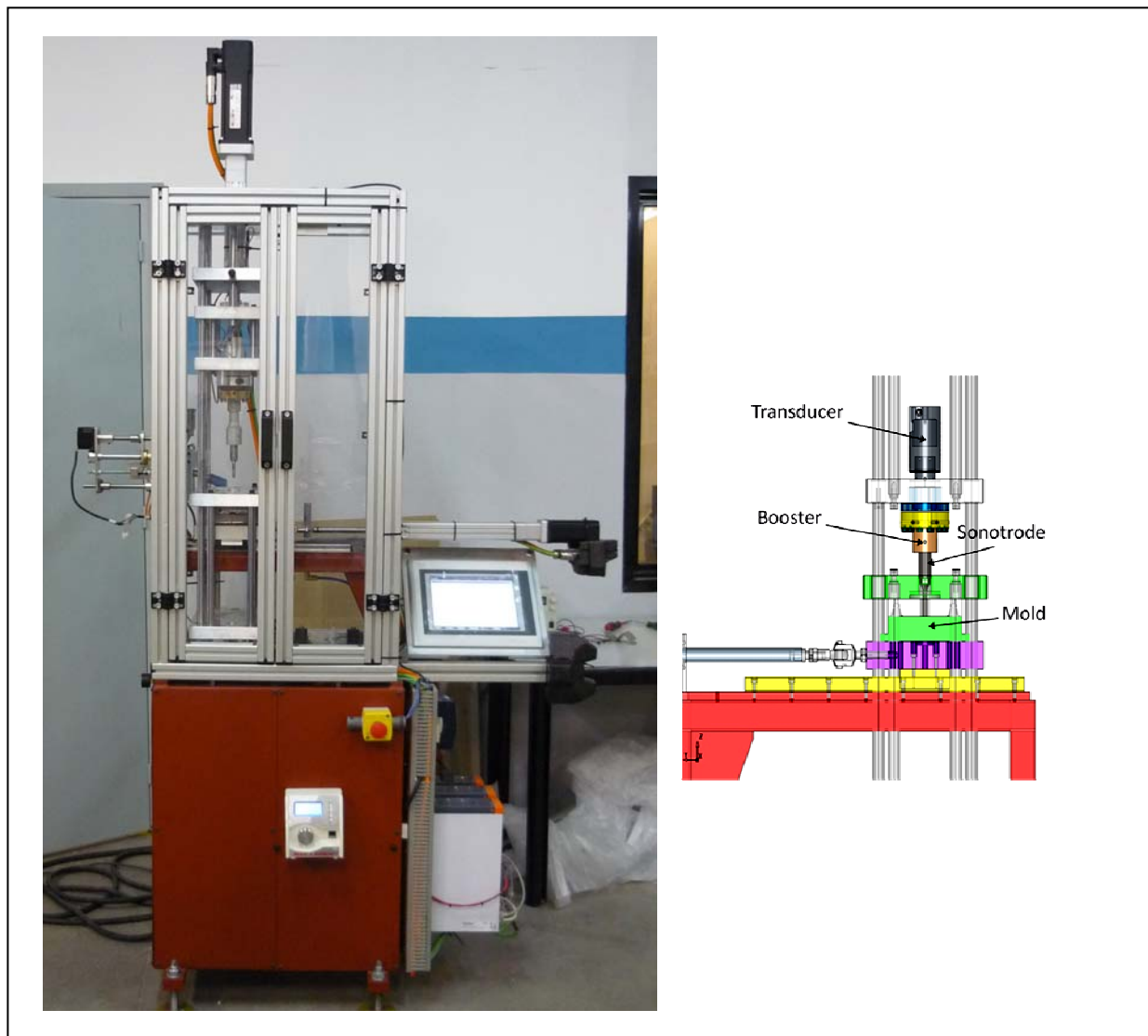


Fig. 1: Picture on the left presents the prototype built in the Sonoplast project, the picture on the right shows the assembly of the ultrasonic unit.

The mould concept has been redesigned to fulfil the requirements of the ultrasound moulding process. This new design, patented by Ascamm, presents three main different structural features. The **figure 2** shows the mould design developed for the new technology.

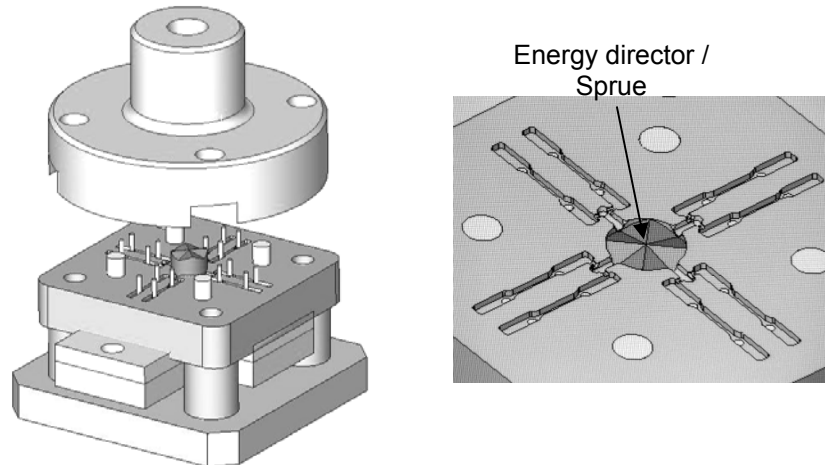


Fig. 2: Mould design developed for the new technology

According to this new concept, the mould is fed with the material on solid status. Therefore, the plastic is melted inside the mould, in a compartment here named plastification chamber. This is the unit where the ultrasound is transmitted from the sonotrodo to the polymer.

Likewise, the new sprue concept allows it behaving as an energy driver as well as part of the ejection system. The energy driver orientates the waves in the right flow. In this way, both melted material and waves move alongside towards the cavities. This also reduces the polymer viscosity.

Moreover, the ejection system was joined to the sprue ejector, making easier the part ejection. Finally the feeding channels which are filled by melted polymer during the filling process provide a resonance box effect over the melted polymer helping the process since it maintains the proper viscosity.

RESULTS

The experimental work led us to define the most important variables of the new ultrasound moulding process and their impact on the part quality:

- **Material dosage volume or weight (g):** is the amount of material that the machine will melt per shot.
- **Amplitude (μm):** is the amplitude of the axial vibration movement that sonotrode tip has when vibration is occurring at 30KHz. This movement helps to control the amount of energy that the system provides to the polymer in order to melt it and to reach the appropriate flow properties for the cavities filling.
- **Pressure under ultrasound (MPa):** is the pressure that sonotrode tip provides to the material while ultrasound is occurring.
- **Ultrasound time (s):** is the total ultrasound time used for plastification.
- **Cooling pressure (MPa):** is the pressure applied since the ultrasound stops until sonotrode lifts. Similar to the packing pressure in conventional injection.
- **Cooling time (s):** is the time necessary to cool down the sample. Similar to cooling time in conventional injection moulding

Compared to conventional injection process, the new ultrasound moulding process presents a reduced number of process parameters that assure the quality of the part. In addition, the new technology provides an easier and simpler way to control them, resulting in an enhanced repeatability. At the same time, the simplicity in the machine control makes feasible the construction of a machine several times smaller than a conventional microinjection machine.

The injection cycle starts with the mould already closed and loaded with the polymer. Then, the sonotrode goes down until touching the material, triggering the ultrasounds. While the ultrasound is in action, the sonotrode provides the necessary pressure to force the material to flow toward the cavities. As soon as the sonotrode stops, both cooling time and cooling pressure take place. Subsequently, the sonotrode goes up to its original position, starting a new cycle. The **Figure 3** presents a scheme of the transversal view of the system mould-sonotrode at different steps during the melting process. It is possible to see the movement of the sonotrode into the mould.

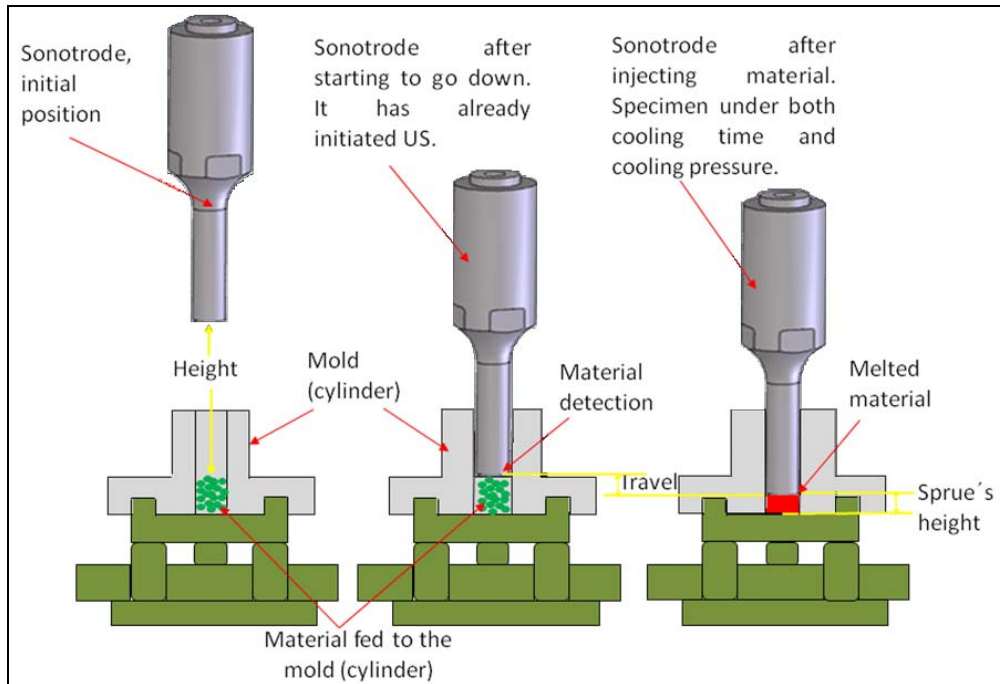


Fig. 3: Scheme of the transversal view of the system mould-sonotrode at different steps during the melting process

The melting process of a polymer in injection by ultrasounds does not require neither conventional electrical heaters nor a reciprocating screw. The ultrasound melting process of a polymer can be understood as the total acoustic energy applied to the material, part of it is partly transformed into vibration energy (through the mould and surroundings) while another part is consumed by the material, dissipating it as heat and consequently melting the polymer.

a. PERFORMANCE VALIDATION

In this part of the work, the objective was to compare the ultrasound mould injection technology with conventional processes applied to the production of mini and microparts. To demonstrate its commercial potential, the study was carried out based on market requirements. The parameters taken into consideration for this were the machine performance in terms of cycle time, material saving, power consumption compared with a conventional injection machine producing the same piece.

In order to this, the whole consortium was asked to indicate an application as a real case for study. Thus, the demonstrator suggested was a part used to perform laboratory tests on mice. It fastens mice's veins for simulating high pressure, in this way allowing carrying out studies regarding high level of cholesterol.

This is a very small product. Due to the way conventional injection molding machines work, a relatively large sprue is needed to its production. To the present, the pieces are produced by

conventional injection with a shot-weight of 1.686g per injection. The piece itself has an average weight ranging between 0,433 μ g and 0,708 μ g, therefore weighing next to nothing compared with the amount of total material used. The **Figure 4** illustrates the current design of the piece chosen as demonstration.

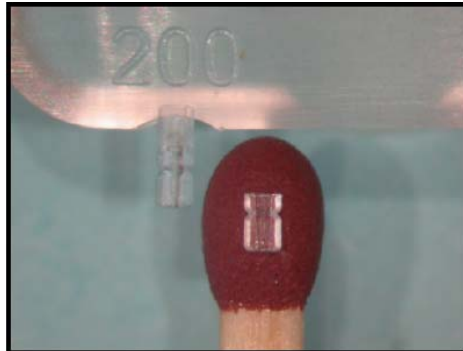


Fig. 4: Current design of the piece chosen to the demonstration

The **Table 1** presents all the control parameters information used to produce the samples in both conventional injection as well as ultrasound mould injection.

Conventional injection		Injection by ultrasound	
Shot weight (g)	1.686	Shot weight (g)	0.085
Temperature (°C)	265-260-255	Amplitude (μ m)	43
Injection pressure (bar)	650	US Pressure (bar)	101
Packpressure (bar)	30	Cooling pressure (bar)	174
Cooling time (s)	15	Cooling time (s)	2.75
Injection speed (mm ³ /s)	53	US time (s)	3.00
Clamping force (N)	100000	Clamping force (N)	1200
Cycles time (s)	21	Cycles time (s)	31

Tab 1. Parameters used to produce the bench piece in conventional injection and ultrasound injection

• Replication capacity

The **Figure 5** shows a comparison made by a microscope (x150) between the samples manufactured by conventional injection and injection by ultrasound to evaluate mould replication capacity.

Comparing the pictures, in general the replication of the pieces is satisfactory. The pieces did not show any signal of degradation process (dark points) as well as the material filled perfectly the cavities. Nevertheless, there are certain tooling aspects about the mould to comment:

- The tool left marks on its path, all over the pieces.
- There is a flash at the top of the pieces, due to a deficiency in coupling between the mould parts when they were drilled.

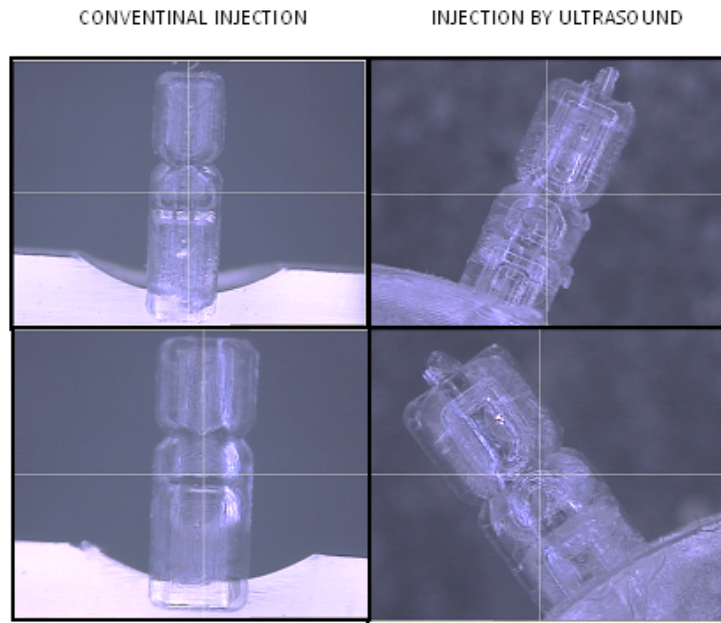


Fig. 5: Comparison made by a microscope between the samples manufactured by conventional injection (left) and injection by ultrasound (right)

- Rheological tests**

Raw material in micro granule shape, ultrasound treated samples and conventional injection moulded samples were arranged. All sample types were characterized by a plate-plate-rheometer. Measurements of the raw material were implemented at 238°C. All three sample types were determined at the same conditions. For comparison of all sample measurements the tan delta was used. It is the quotient of the loss modulus G'' to storage modulus G' and therefore less susceptible for measurement faults. The **Figure 6** presents the results for the Rheological test for all the materials.

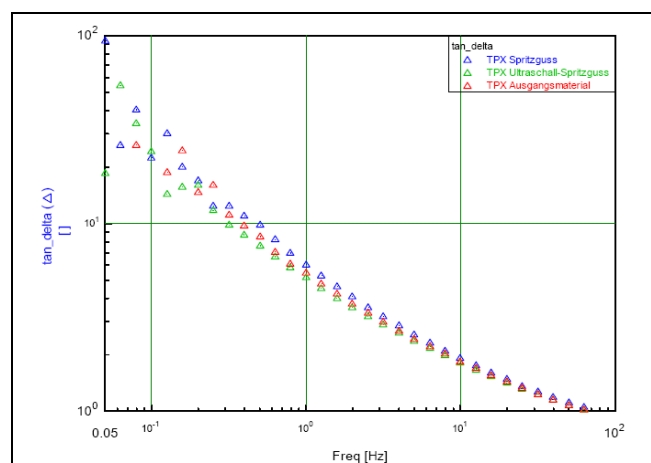


Fig. 6: Rheological test for all the materials

The figure above shows tan delta of the untreated micro granule (red), of the ultrasound treated samples (green) and the conventional injection molded samples (blue). The comparison of all determined results shows no deviation. All charts whether ultrasound treated or injection molded as well as untreated material have nearly the same characteristic. Therefore with the described method there is no degradation of the ultrasound treated material noticeable.

- **Cycle time**

Although the plastification step in the ultrasound injection machine is highly shorter compared with conventional injection, the total cycle time is 31 seconds because of the feeding system time. This means further efforts have to be implemented over the feeding system in order to decrease this cycle time and make it more competitive towards conventional injection process cycle time values.

On the other hand, as it can be seen from the **Table 1** above, the ultrasound time takes only 3 seconds more than conventional injection cycle time. It is important to stress that, in spite of this, the sum of ultrasound time and cooling time in ultrasound moulding injection is slightly lower than a normal conventional injection cycle time. With this new technology, the ultrasound time includes the plastification process, which is quite different for the calculation of conventional injection cycle time. This is a benefit provided by the technology because it decreases the possibility of material thermal degradation.

- **Material savings**

The **Figure 7** shows a comparison between the samples made by conventional injection and ultrasound injection.



Fig. 7: Comparison between the samples made by conventional injection (right) and ultrasound injection (left)

It is possible to see immediately the enormous reduction of sprue material. In the case of the conventional injection sample, both sprue and pieces sum up 1.686g. In the other hand, through the ultrasound injection, the sample has only 0.085g, representing a **material saving over 95%**.

- **Power and energy saving**

The project also developed a procedure to determinate the SEC (Specific Energy Consumption) for the new machine. That was achieved by calculating the production rate for the individual machine that is used to manufacture the piece chosen in terms of kW/kg/h (kWh/kg). Keeping in mind the piece is manufactured with 0,085g and the cycle time was 31s, the energy consumption related to the amount of material was **14,44kWh/kg**. Previous experiences with the production of this sample in conventional injection process show values over **60kWh/kg**, representing a **total reduction over 75% in the total energy** required for the process.

In terms of conventional injection moulding technology, the sample chosen is extremely inefficient due to its mass and cycle time. Actually compared with other reports of average usage on injection molding this ranged from near 3kWh/kg up to a maximum of 8kWh/kg.

In order to analyze these results, it is possible to suggest some reasons of such inefficiencies:

- The runner and the sprue needed to injection mould the product itself is slowing down the cycle time dramatically.
- The major part of the injection moulded polymer will eventually be thrown away after the production.

Comparing both conventional and ultrasound injection processes, it is not noticeable a great difference in terms of energy consumption per amount of material to be melted. However, considering the new ultrasound machine present a significant reduction in the use of raw material, it therefore presents a much higher efficiency.